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Study of Clay Minerals of the Sediments of the Jayanti Estuary, Shariatpur-Barisal, Bangladesh

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Abstract

The present X-ray diffraction analysis deciphers that the clay sized minerals of the Jayanti estuary are comprised principally of illite in combination with varying amounts of kaolinite, chlorite, quartz and feldspar. The amount of illite is highest in the headward part and lowest in the mouth of the Jayanti estuary. The positive correlation of feldspar with quartz reveals that they originated from the same source. A huge amount of clay size minerals is transported in suspension to the Bay of Bengal by the ebb tide, whereas floodtide owes its suspended load from offshore marine environment. As the velocity of the incoming floodtide is decreased, the clay size minerals deposited in the basin. The clay mineral assemblages suggest their origin from Precambrian metamorphic rocks, acid igneous rocks and sandstones and shales of Paleozoic to Cenozoic age. Minor to trace amounts of calcite and dolomite are indicative of mechanical weathering of limestone in the source area.

Keywords: X-ray Diffraction, Jayanti Estuary, Illite, Kaolinite, Chlorite and Mechanical Weathering.

Introduction

The clay mineral assemblages may be useful for determining variations in the source areas in such sedimentologically homogeneous materials. The illite clay assemblage with variable amounts of kaolinite and chlorite is the simplest of many associations characterizing the estuarine sediments of Indian Ocean. It is widespread both in continental and marine facies (Jeans, 1994). Sedimentological studies of the study area reveal that the deposits are mainly characterized by the fluvial and marine sediments (Saha et al., 2019). The illite clay assemblages represent the major fine-grained sediments at the time of deposition. Sediments from the Godavari, Krishna and Cauveri estuary contain montmorillonite, illite and chlorite whereas Mahanadi estuarine sediments contain illite, montmorillonite and kaolonite with no significant lateral variations (Kumar and Rao, 1987). Little smectite (7%) but high concentrations of illite (70%) are seen in the Hooghly estuary (Rao *et al*.,1988). In the same area Mallik (1976) found equal amounts of illite and kaolinite with traces of chlorite and quartz. The present work has been concerned within the of Jayanti branch of the mighty Meghna estuary that finally empties Bay of Bengal (Fig.1).

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The main objective of this research is to determine the distribution of clay size (<2μm) minerals, their depositional model and the source of clay minerals---whether the clay minerals are detrital or formed contemporaneously and paleoclimate.

Geological Setting

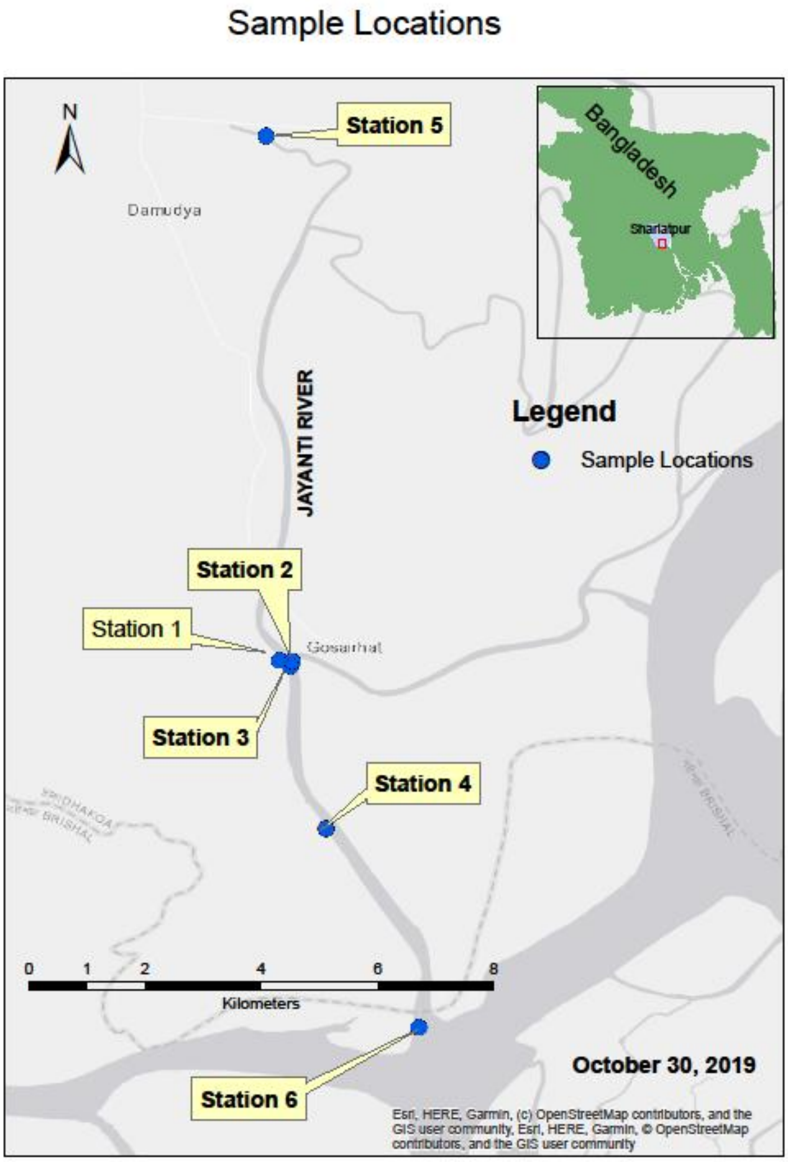
The Jayantiis a branch of theMeghna river. The Meghna is a well-known estuary and drains into the Bay of Bengal. The Ganges, Brahmaputra and Meghna river system transports world's largest amount of terrigeneous sediments in suspension and these are estimated as 1.7 billion tons a year (Milliman and Meade, 1983; Kudrass et al., 2001). The sediments are characterized by the dominance of silt and clay with 10-20% very fine sand (Thorne et al., 1993).

The Jayantiestuarine reach is more or less funnel shaped body of water influenced by semidiurnal tides. A characteristic daily inequality is recorded between the two flood (and ebb) tides. The mean tidal range is low, with numerical value 91 cm and varies within a wide limit from 10 to 280 cm. the duration of ebb tide is longer than that of flood tide suggesting a fluvialdominance in the study area. Seasonal floods often discharge of 3 to 5 orders of magnitude larger than the mean discharge. The flow is always tidal even during large river floods.

Subsurface information from Hizla-Muladi well (well-1, depth 4732m and well-2 depth 4556m) shows that lithocolumn is constituted the rocks of Surma Group, Tipam Group, DupiTila Formation and Alluvium from base to top (Imam, 1986; Reimann,1993). The Surma Group of Miocene age composed mainly of shale and sandstone where shale: sand ratio tends to be remarkably as high as 10:1. Sandstone with some interbedded shale constitutes the rocks of Tipam Group. The DupiTila formation is characterized the deposition of medium to coarse grained gray to yellow sandstone with clay galls and claystone with subordinate siltstone.

Sand, silt, clay, organic matter and their admixtures constitute the rocks of Alluvium. These sediments are extensively exposed along the both banks of the investigated area. Stratigraphically deltaic sand deposits (dsd) and deltaic silt deposits (dsl) constitute the northern and western portion, whereas estuarine deposits (de) comprise the southern part of the study area (Alam et al., 1990).

Sedimentological study reveals a total of seven distinct lithofacies and these are namely: i) Facies A: Finely laminated sand and silt, ii) Facies B: Silty rhythmites, iii) Facies C: Sandy rhythmites, iv) Facies D: Clayey rhythmites, v) Facies E: Faintly laminated to massive clay with peds, vi) Facies F: Ripple laminated silt and clay and vii) Facies G: Ripple laminated sands which are clearly shown in Figure 2 and 3 (Saha, 2000; Roy et al.,2004). A relatively stable estuarine setup was suggested during the deposition of facies A to D. The deposition of facies E and F show a gradual retreat of the estuary towards the south in expense of delta progradation. Only facies G indicates an intertidal sand bar deposit in the present estuarine channel.



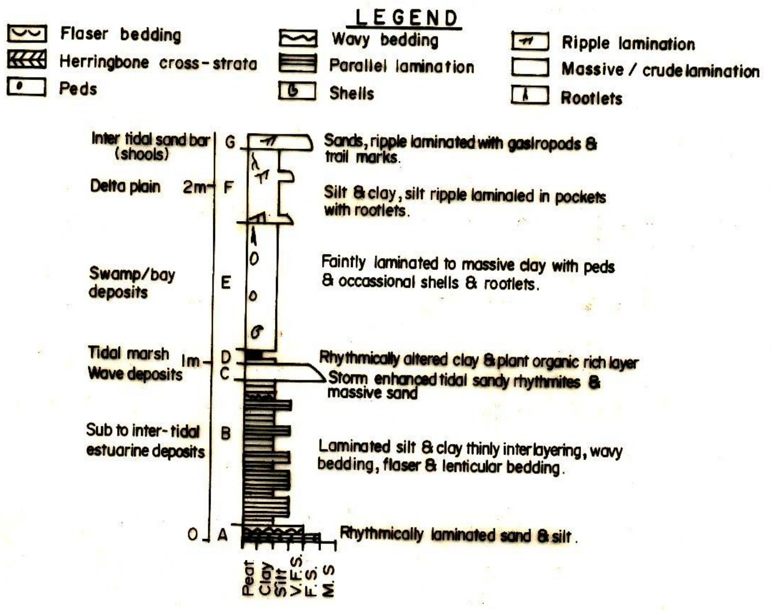


Fig. 2 : Schematic facies model of vertical sequences in a river dominated estuary.

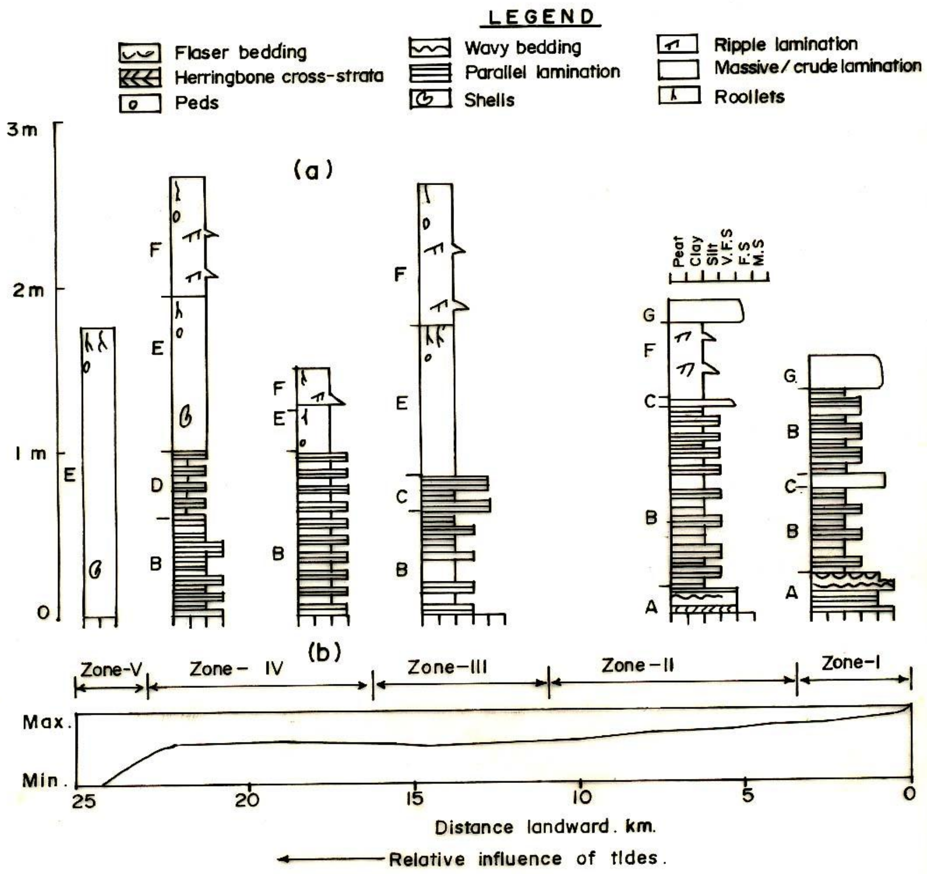


Fig.- 3 : Zonations of estuarine sequences based on sedimentological and stratigraphic evidences.

A graphic indication of changes in the relative influence of tides throughout the estuary (based on facies sequences).

Table 1
A summary of lithofacies, their descriptions and interpretations for the study area

Facies	Codes	Description	Interpretation
Finely laminated sand and silt	**A**	Alternating layers of medium to very fine, yellowish brown to grey coloured sand and silt. The sand layer is structured by ripple cross laminations and flaser bedding.	Estuarine deposits
Silty rhythmites	**B**	This facies is composed of alternating layers of silt and clay. These are parallel laminated and rhythmically altered. Silt layers are thinner, whereas the clay layers are thick.	Intertidal estuarine deposits.
Sandy rhythmites	**C**	Alternate layers of medium to fine grained sands and clay. Sand is yellowish brown in colour, micaceous.	Estuarine deposits
Clayey rhythmites	**D**	Alternating layers of clay and organic matter. The organic rich layers are dominated by black plant materials and rootlets.	Tidal marsh environment
Faintly laminated to massive clay with peds	**E**	This facies is characterized by clay. The sediments are occasionally bioturbated. Ferruginous materials are locally present.	Freshwater swamp or bay deposits
Ripple laminated silt and clay	**F**	Clay comprises 80-85% of this facies. Clay is grey to brownish grey in colour, embedded with rootlets	Delta plain deposits
Ripple laminated sands	**G**	Fine grained sands with little amounts of silt, fining upward trend is observed in the lithocolumn. Cross bedding, ripple cross laminations and water recession marks are the main sedimentary structures.	Tidal bar deposits

On the basis of sedimentary structure, morphology and sand+silt : clay ratio the estuary can be subdivided into four morphologic zones, namely mouth, funnel, meander and head. Sand and silt constitute 69% of the estuarine mouth, which is 38% in the funnel zone that extends 3.70 km to 15 km landward from the mouth. In the meander zone admixture of sand and silt comprise 59% of the total stratigraphic column, while in the head sand and silt does into exceed 12% (Figure 4).

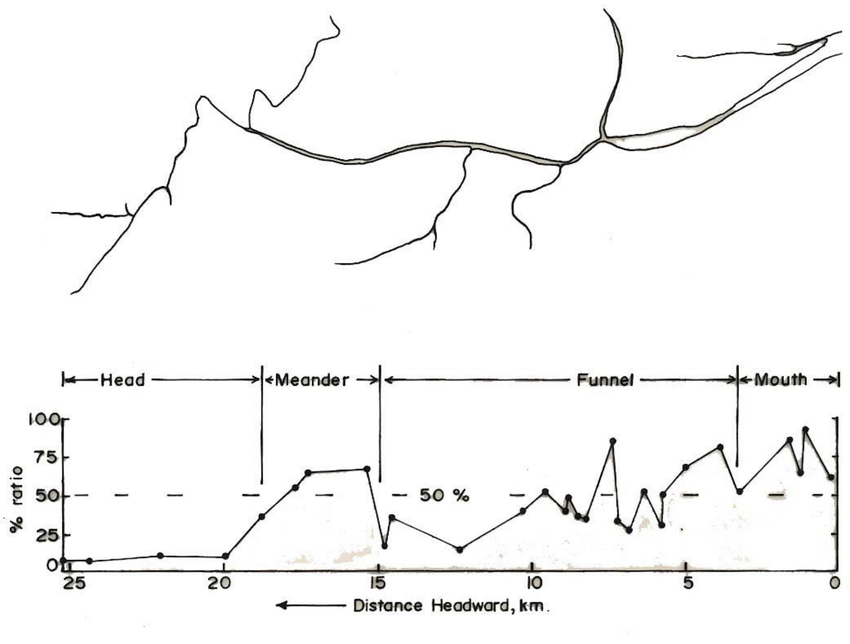


Fig. 4 : Variation of sand+silt:clay ratio with distance headward along the estuary. Morphologic zones closely follow the sand + silt : clay ratios near to 50 %.

Experimental Techniques

Sample preparation

Sediment samples were collected from the both banks of Jayanti branch of the Meghna estuary. Samples were broken into small pieces and were washes in distilled water over a period of 24-76 hours to remove entrained salt. Fines (muds) were then separated from then coarser (sands) fractions by washing through a 63 µm sieve opening. The <2 µm clay fraction was obtained by sedimentation from an aqueous suspension according to Stokes' Law, in presence of 1% sodium hexametaphosphate. Cation saturation and flocculation were induced by adding magnesium chloride. Oriented mounts of the clay fractions were prepared by filtering the clay suspension through ceramic disc using suction onto ceramic tile method as described by Shaw (1972). The clay mounts were then scanned on a JEOL-JDX-8SD X-ray diffractometer (XRD) using Cu-Kα radiation from 2-32° 2Θ in the untreated (air dried), ethylene glycol-solvated and heat treated (550°C) states.

Identification of clay size minerals

The X-ray diffractogram patterns obtained after various treatments of the sample show that the clay fraction is dominated by illite with kaolinite, chlorite quartz and feldspar. In the air-dried state illite is identified by an integral series of peaks with a basal spacing determined from the 002 reflection of ca. 9.82-10.10Å and from the 004 reflection, ca. of 4.98-5.04 Å (Figure 5). On glycolationillite is non-expanding. On heating 550°C illite remains unchanged. Presence of kaolinite in combination with chlorite is recognized by a series of peaks with basal spacing 7.02-7.25 Å. All kaolinites are unaffected by glycolation and on heating to 550°C destroys their crystal structure. Presence of kaolinite was confirmed by basal spacing at 3.57-3.59 Å. Peak values 14.25 Å, 4.73-4.76 Å and 3.54 Å confirm the presence of chlorite, where they do not interference with kaolinite. Quartz is identified in all samples with principal reflections at 4.26 Å and 3.34 Å. Little amounts of feldspar recorded by the peak values 3.24 Å. Minor to trace amounts of calcite and dolomite are recognized at 3.03 Å and 2.89 Å respectively.

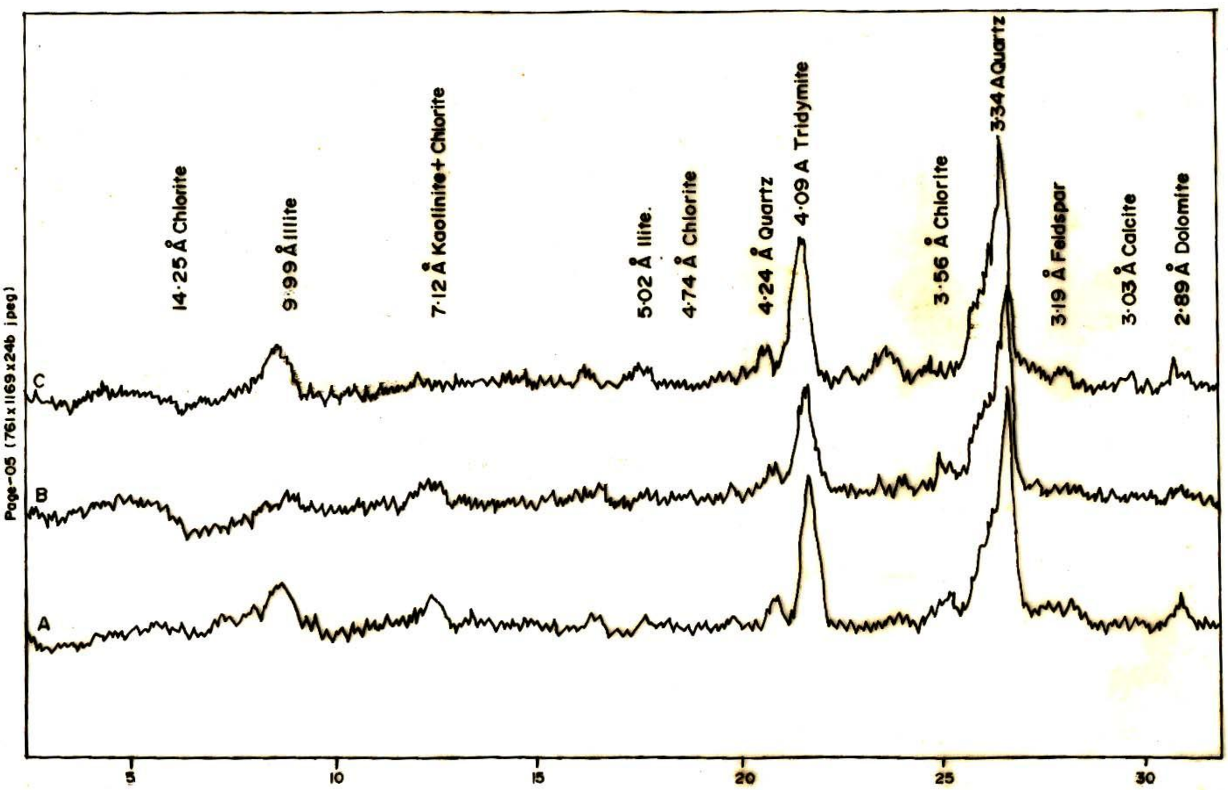


Fig. 5 : XRD Patterns of oriented clay sample, (A) air-dried, (B) ethyline glycolated and (C) 550°C heated states.

Semiquantitative analysis of clay size minerals

Semiquantitative analysis of clay sized minerals (kaolinite, chlorite, illite, quartz, feldspar) were performed using the weighting factors of Department of Geology and Mineral Resources Engineering, Norwegian Institute of Technology (NTH).Peak areas were determined by multiplying the peak height by the peak width at half maximum height. These results were listed in Table 2. Repetitive runs on the same sample may yield a ±5% error; however, this figure does not indicate an accurate percent error for the bulk sample, which theoretically could be as high as 40% for this type of analysis (Segali et al., 1987, 1991).

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Results
Table 2
Relative abundance of clay sized minerals

Sample	Station	Position	Illite	Kaolinite	Chlorite	Quartz	Feldspar
1	31	Mouth	49.85%	18.73%	10.73%	15.47%	5.23%
2	4	Funnel	51.87%	26.60%	7.84%	11.64%	2.04%
3	3	Funnel	51.69%	21.10%	6.52%	17.38%	3.31%
4	2	Funnel	57.87%	21.59%	5.74%	11.16%	3.64%
5	6	Funnel	52.15%	17.73%	11.51%	15.53%	4.08%
6	10	Funnel	45.39%	23.22%	20.74%	9.16%	1.50%
7	19	Meander	42.56%	17.45%	30.54%	7.27%	2.18%
8	24	Head	62.96%	13.12%	7.15%	15.33%	1.44%
Average			51.79%	19.94%	12.60%	12.87%	2.93%

Table-2 shows that illite is the dominant mineral in all of the samples, where the average amount illite is 52%. The mean amount of kaolinite is 20%, chlorite occurs in concentration of 12%, quartz 13% and feldspar 3%. The illite concentration increases from mouth to funnel zone (50% to 58%) and decreases towards the meander zone (43%). The highest amount of illite is recorded in the headward part of the estuary.The concentration of kaolinite is maximum in funnel and decreases both in mouth and head zones. Highest amount of chlorite is noted in meander zone.

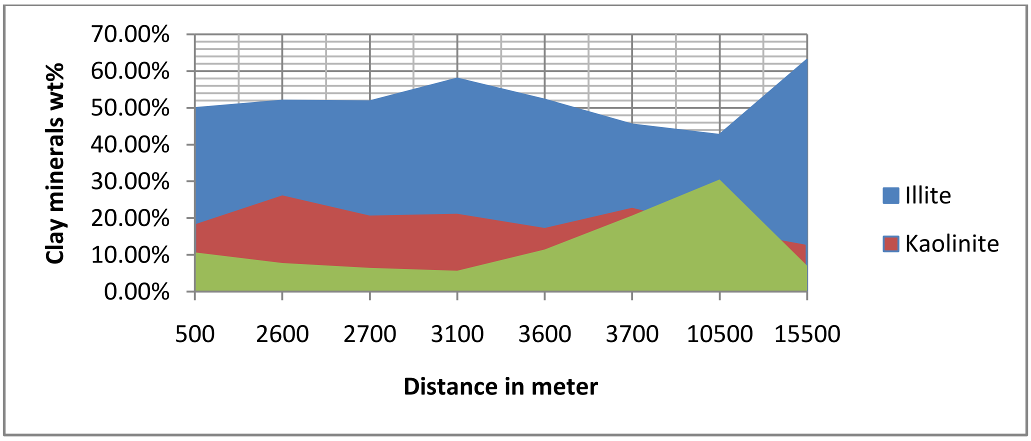

Fig 6 : Distribution of clay minerals vs. distance (distance from the mouth of the estuary)

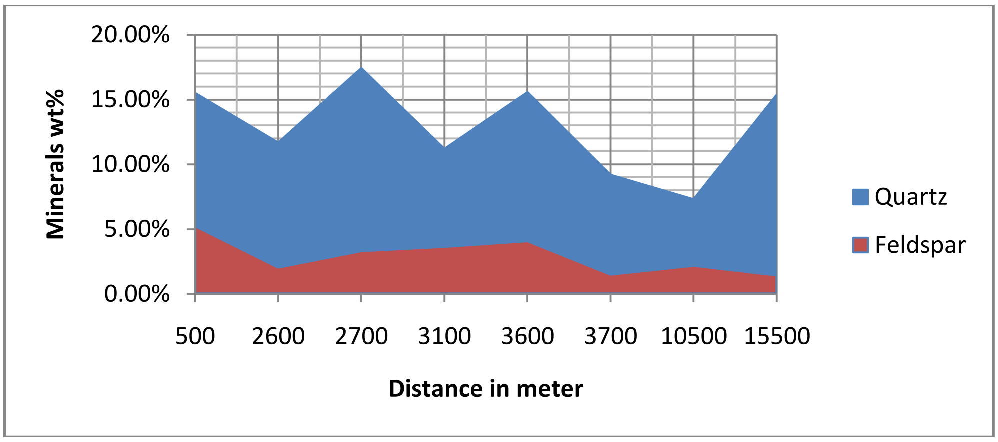

Fig 7 : Distribution of quartz and feldspar vs. distance (distance from the mouth of the estuary)

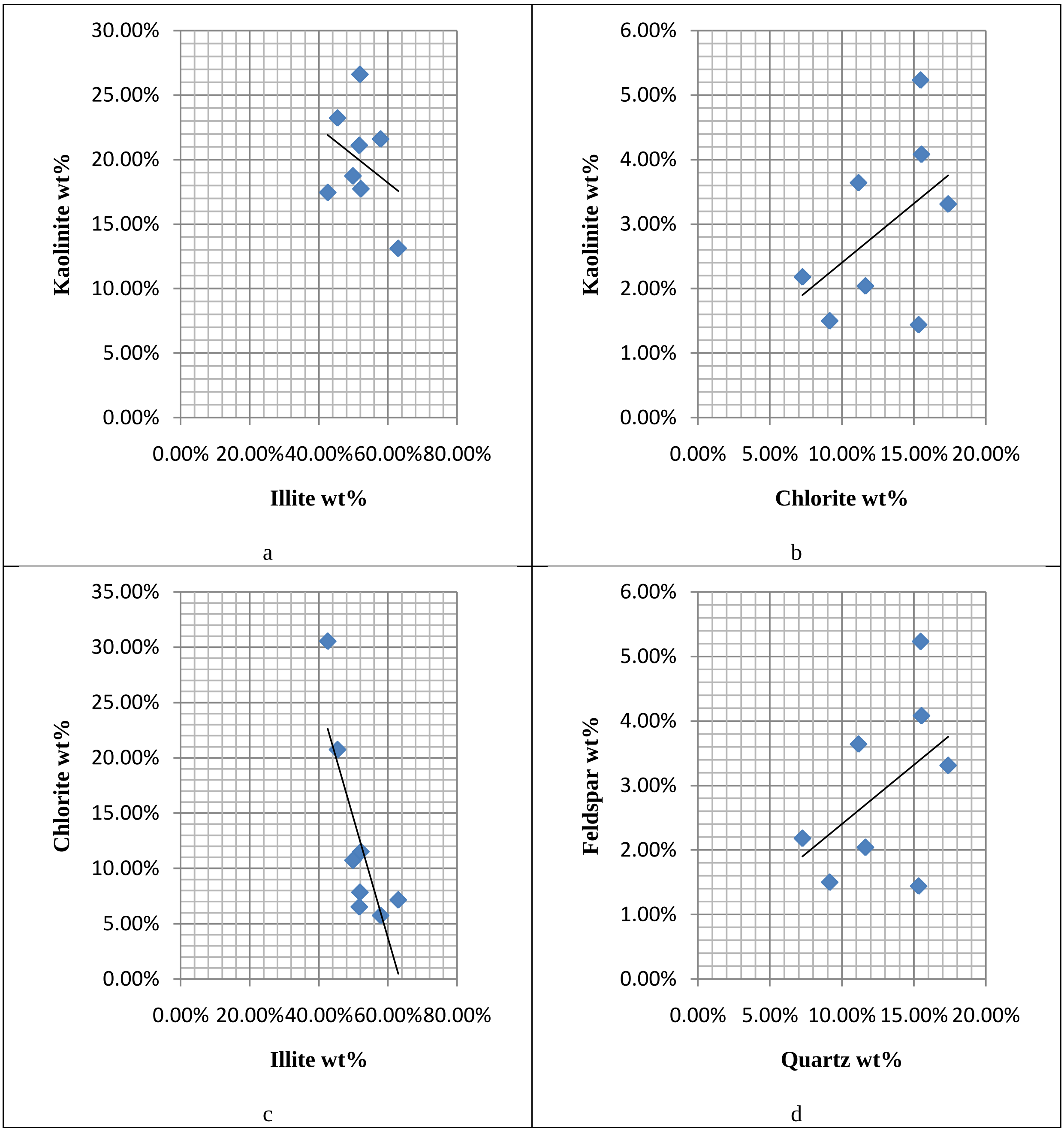

Fig 8 : **a** Kaolinite vs. illite showing a negative correlation, **b** Kaolinite vs. chlorite showing a positive correlation, **c**Chlorite vs. illite showing a negative correlation and **d**Feldspar vs. Quartz showing a positive correlation.

Discussion

The depositional model

In estuaries the lighter fresh water flows seaward on the top of the denser saline water. If the incoming flood tide exceeds the velocity of outgoing ebb tide the resultant flow is towards the land. The magnitude of the river flow and the tide flow controls the position of the interface between the fresh water and saline water. The interface moves toward the sea during the ebb tidal flow and towards the land during the flood tidal flow. The two opposite flowing currents transport suspended sediments in opposite directions.

A huge amount of fine detrital sediment load is transported in suspension to the Bay of Bengal by the ebb tidal flow. These suspended sediments are obtained by the erosion of the drainage basin and clay mineral suite. The flood tide flows obtain their suspended load from the offshore marine environments that are deposited by the ebbtidal flow within the offshore. The river water flowing towards the sea over the lower saline layer, some of the particles settle out of the upper fresh water into the deeper seawater and are carried landward.The rate of flocculation decreases in the deeper saline water while much of the initial flocculation occurs in the upper freshwater. When the velocity of the lower saline water column is ceased the clay minerals are deposited near the freshwater-saline water transition (Weaver, 1989). The sediment is subjected to erosion and resuspended during both the incoming floodtide and outgoing ebbtide and settle during the slack water. When sediment is eroded and resuspended differential clay minerals by size comes into the play (Gibbs, 1977). Illite, kaolinite and chlorite are deposited from such differential suspension.Illite is more stable with lower salinity (Edzwald and O'Melia, 1974).

The presence of non-expanding illite, kaolinite and chlorite lead to almost non-plastic behaviour and low swelling potential of the studied sediments (Das, 1995). The positive correlation of feldspar with quartz reveals that they originated from the same source.

Sources of clay sized minerals

From the mineralogical study of the estuarine sediments, it is evident that these sediments are derived not from single source but from both igneous and metamorphic rocks and also from paleosediments. Detrital illite is the dominant mineral in the study area and suggests their derivation relatively unweathered granitic terrain (Segali and Kuchl, 1992). The major contribution comes from the high land rivers that drain Precambrian metamorphic rocks, acidic intrusive igneous rocks and sandstones and shales of Paleozoic to Cenozoic age. Some diagenetic illites may also occur through the alteration of feldspars and other clay minerals (Ruiz Cruz, 1994). Lippmann and Berthold described that illitic clay may be derived from much older sediments or low-grade metamorphic rocks.Higher amounts of illite and chlorite in the deposits suggest a dominance of physical weathering at that time of deposition (Heroy, et al., 2001). Kaolinite is weathering product of feldspar and other silicates, produced by ion stripping in power p^Henvironment. The formation of kaolinte is enhanced by the agricultural activities of the study area. The parent rocks from which chlorite generated are metamorphosed rocks, mainly schist of Precambrian age. The minor to trace amount of calcite and dolomite are indicative of their formation by mechanical weathering.

Conclusion

1. The clay size mineral assemblage is characterized by the dominance of illite (51.79%) with kaolinite (19.94%), chlorite (12.60%), quartz (12.87%) and feldspar (2.93%). Deposition of illite denotes the major fine-grained detritus during the deposition and forms the predominant component of argillaceous deposits.
2. An enormous amount of fine detrital sediments (<2 µm size minerals) are transported in suspension to the Bay of Bengal by the ebb tidal flow. The flood tide flow achieves their suspended load from the offshore marine environments that are deposited by the rivers to the offshore.
3. The provenance source area of the of the clay minerals is chiefly constituted by Precambrian metamorphic rocks, acid intrusive igneous rocks and sandstones and shales of Paleozoic to Cenozoic age. Large amounts of kaolinite supply come from the Brahmaputra River. Some diagenetic illites may also appear through alteration of feldspars and other clay minerals and from both micas and feldspars suggesting alkaline conditions.

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